

*RESPONSE ACQUISITION WITH DELAYED
REINFORCEMENT: A COMPARISON OF
TWO-LEVER PROCEDURES*

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Groups of 8 experimentally naive rats were exposed during 8-hr sessions to resetting delay procedures in which responses on one lever (the reinforcement lever) produced water after a delay of 8, 16, 32, or 64 s. For rats in one condition, responses on a second (no-consequences) lever had no programmed consequences. For rats in another condition, responses on a second (cancellation) lever during a delay initiated by a response on the reinforcement lever prevented delivery of the scheduled reinforcer; responses on the cancellation lever at other times had no programmed consequences. Under both conditions and at all delays, most subjects emitted more responses on the reinforcement lever than did control rats that never received water emitted on either lever. At 8-s delays, both conditions engendered substantially more responding on the reinforcement lever than on the other lever, and performance closely resembled that of immediate-reinforcement controls. At delays of 16 and 32 s, however, there was clear differential responding on the two levers under the reinforcement condition but not under the other condition. When the delay was 64 s, differential responding on the two levers did not occur consistently under either condition. These findings provide strong evidence that the behavior of rats is sensitive to consequences delayed by 8, 16, and 32 s, but only equivocal evidence of such sensitivity to consequences delayed 64 s. They also indicate that acquisition depends, in part, on the measure of performance used to index it.

Key words: response acquisition, delayed reinforcement, water, lever press, rats

Previous studies have shown that rats will acquire lever-pressing behavior with reinforcement delayed by up to approximately 30 s in the absence of shaping or autoshaping (Byrne, LeSage, & Poling, 1997; Critchfield & Lattal, 1993; Dickinson, Watt, & Griffiths, 1992; Lattal & Gleason, 1990; LeSage, Byrne, & Poling, 1996; van Haaren, 1992; Wilkenfield, Nickel, Blakely, & Poling, 1992). The study of delayed reinforcement raises difficult theoretical and procedural issues (see Lattal, 1987), and there is no ideal assay for studying the effects of reinforcement delay on response acquisition. As Wilkenfield et al. (1992) discuss, nonresetting delay procedures allow obtained delays to be shorter than nominal delays; therefore, they are not especially useful for parametric evaluations of the effects of delay of reinforcement on response acquisition.

Resetting delay procedures, which can be construed as tandem fixed-ratio (FR) 1 not-

responding-greater-than t ($\bar{R} > t$) schedules, do ensure that nominal and obtained delays are equivalent. But rate of responding is not a good index of sensitivity to programmed contingencies under such arrangements. Arranging an $\bar{R} > t$ (also known as a differential-reinforcement-of-other-behavior, or DRO) schedule reduces the rate of occurrence of established operants, and the magnitude of the response reduction is directly related to the length of t (e.g., Zeiler, 1971, 1976, 1979). The value of t defines the delay of reinforcement under resetting procedures and, at long delays, subjects are exposed to both a powerful response-reducing contingency and to delayed reinforcement. Given this, it is perhaps not surprising that prior studies have shown that, at resetting delays of 16 and 32 s, rats emitted as many, or more, responses on a lever on which responses had no programmed consequences (the inoperative lever) as on a lever that produced food (or water) (the operative lever) (LeSage et al., 1996; Wilkenfield et al., 1992).

One interpretation of these findings is that the rats' behavior was not sensitive to its consequences at these delays. In relatively small chambers, as were used in those studies, oc-

The reported research was conducted as part of the MA thesis of the first author and was partially supported by National Institute on Drug Abuse Grants DA 07869 and DA 05802.

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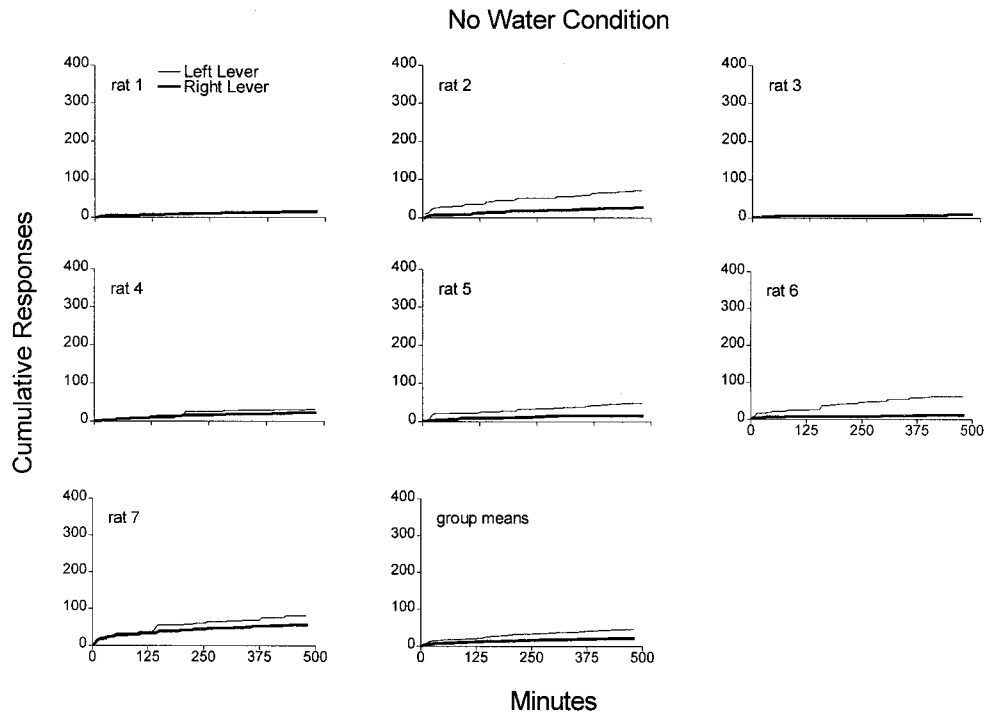


Fig. 1. Cumulative responses on the left and right levers by individual rats across 8-hr sessions. Group means are also shown. Presses on neither lever had any programmed consequences, and water was never delivered.

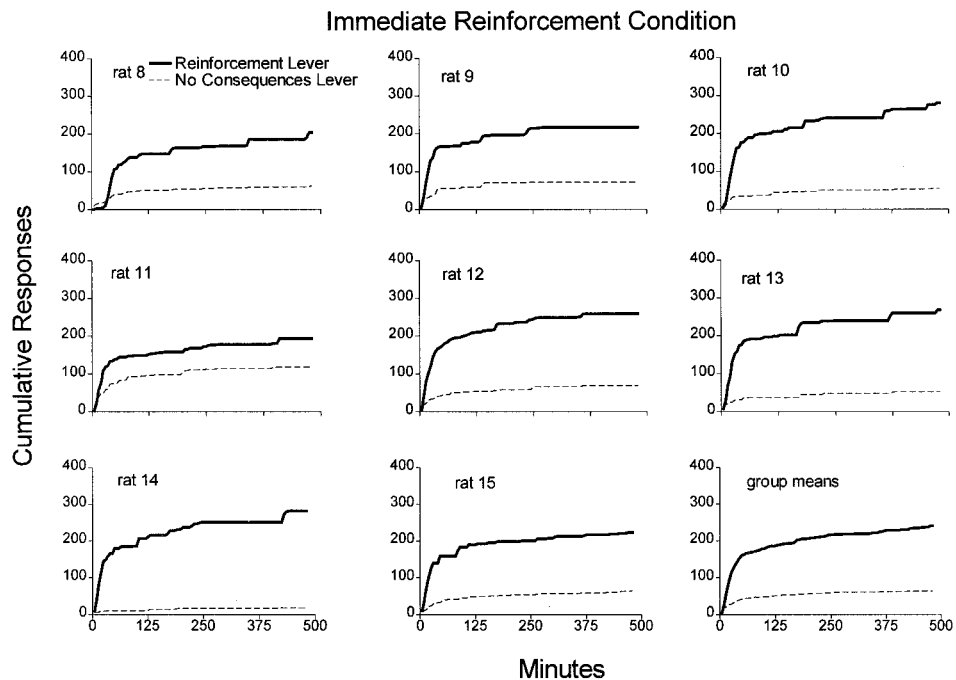


Fig. 2. Cumulative responses on the reinforcement and no-consequences levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced food immediately. Presses on the no-consequences lever had no programmed effects.

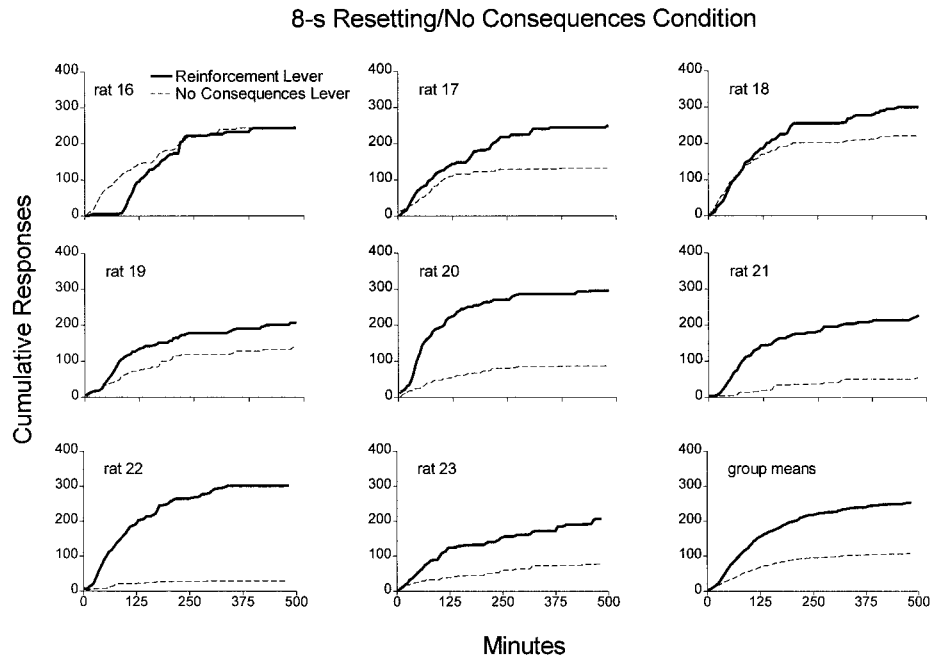


Fig. 3. Cumulative responses on the reinforcement and no-consequences levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 8 s; responses during the delay reset the interval. Presses on the no-consequences lever had no programmed effects.

casional lever presses are likely to occur. Those responses produce the putative reinforcer (food or water). The activity level of deprived animals that occasionally receive food (or water) may increase, and lever pressing may thereby be more likely even though no process of reinforcement is involved. If this were the case, similar levels of responding should occur on the two levers, which require similar response topographies. This possibility does not appear likely, given that Dickinson et al. (1992) and LeSage et al. (1996) observed little lever pressing by yoked-control rats that received food whenever food was earned under nonresetting delay procedures by master partners and for which lever presses had no programmed consequences. Performance of yoked-control rats has not, however, been compared to that of master rats exposed to resetting delay procedures.

Another interpretation was offered by Wilkenfield et al. (1992), who proposed that both operative-lever and inoperative-lever responses were strengthened by food delivery (see also Catania, 1971). Reinforcement was adventitious in the latter case, but under the resetting procedure delays were nonetheless

shorter for inoperative-lever responses. Moreover, the $\bar{R} > t$ contingency was incompatible with high levels of responding on the operative lever and may have indirectly increased the level of inoperative-lever responding. For these reasons, it is not surprising that operative-lever responding did not exceed inoperative-lever responding at some delays.

Comparing levels of responding on operative and inoperative levers obviously does not provide an uncontaminated index of sensitivity to reinforcement contingencies under resetting delay procedures. To provide a better index of such sensitivity, the present procedure examined acquisition of lever pressing by rats under conditions in which responses on one lever (the reinforcement lever) produced water after a resetting delay of 8, 16, 32, or 64 s, and responses on a second lever (the cancellation lever) prevented any scheduled water delivery. Therefore, responses on this lever never produced water and were never followed by water by a delay shorter than that programmed on the operative lever. Substantial differences in levels of responding on the reinforcement and cancellation levers would provide relatively clear evidence of sen-

sitivity to delayed reinforcement. To determine whether this comparison would yield results different from those obtained when responses on an operative (reinforcement) and inoperative (no-consequences) lever are compared, the present study also arranged 8-, 16-, 32-, and 64-s resetting delays under conditions like those arranged in previous studies (LeSage *et al.*, 1996; Wilkenfield *et al.*, 1996). As noted, those studies provided only equivocal evidence of response acquisition at delays of 16 and 32 s.

METHOD

Subjects

Eighty experimentally naive Sprague-Dawley rats, approximately 60 days of age, were used as subjects. The rats were water deprived as described below and were housed individually with unlimited access to food in a colony area with a 12:12-hr light/dark cycle.

Apparatus

Eight MED Associates operant conditioning chambers were used. The chambers were 28 cm long by 21 cm wide by 21 cm high. During response-acquisition sessions, two response levers separated by 8.5 cm were mounted on the front panel 7 cm above the chamber floor. The levers were removed during dipper-training sessions. A minimum force of 0.14 N was required to operate the levers. A receptacle located in the center of the front panel 3 cm above the chamber floor allowed access to a dipper filled with 0.1 ml of tap water. Chambers were illuminated by a 7-W white bulb located on the ceiling. An exhaust fan in each chamber masked extraneous noise and provided ventilation. Programming of experimental events and data recording were controlled by a microcomputer equipped with MED-PC[®] software.

Procedure

All subjects were water deprived for 24 hr prior to one dipper-training session. Dipper-training sessions were 90 min in length. During these sessions, water was delivered under a variable-time (VT) 60-s schedule. Under this schedule, 4-s dipper presentations occurred randomly on average once every 60 s, regardless of the subject's behavior. All rats

were observed to drink from the dipper by the end of the session. At the end of dipper-training sessions, rats were returned to their home cages and given 20-min access to water.

Twenty-four hours after dipper training, subjects were exposed to one response-acquisition session. Response-acquisition sessions began at approximately 10:00 p.m. and lasted for 8 hr. Rats were randomly assigned to each of 10 acquisition conditions (groups), with 8 rats in each group. Subjects in the resetting/no-consequences condition were exposed to a tandem FR 1 $\bar{R} > t$ schedule on the reinforcement lever. Here, the first response initiated a delay of t s, after which water was delivered for 4 s. Responses on the reinforcement lever during the delay reset the interval. Values of t were 8, 16, 32, and 64 s for various groups. Responses on the no-consequences lever had no programmed effects. The left lever was designated as the reinforcement lever for 4 randomly selected rats in each group, and the right lever was designated as the reinforcement lever for the remaining rats.

Subjects in the resetting/cancellation condition also were exposed to a tandem FR 1 $\bar{R} > t$ schedule on the reinforcement lever. In addition, if a response occurred on the other (cancellation) lever during a delay (t) interval, the scheduled water delivery did not occur. Responses on this lever at other times had no scheduled consequences, but were recorded. Delay values of 8, 16, 32, and 64 s were arranged for various groups. The left lever was designated as the reinforcement lever for 4 randomly selected rats in each group.

There were two control conditions. In one, subjects immediately received 4-s water deliveries following responses on the reinforcement lever, and responses on the other lever had no programmed consequences. The left lever was designated as the reinforcement lever for 4 randomly selected rats in this group. In the second control condition, there were no programmed consequences for responses on either lever, and water was never delivered. One chamber malfunctioned under this condition; therefore, only 7 rats were exposed to it.

Under all conditions, responses on the two levers were recorded in 5-min bins across the course of the session. Total water deliveries during each session were also recorded.

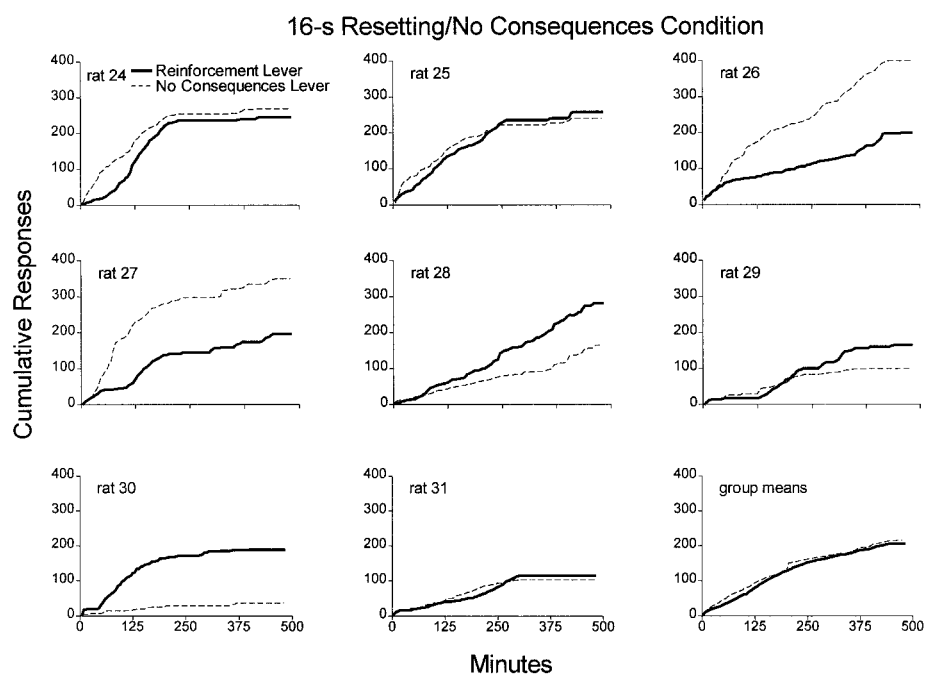


Fig. 4. Cumulative responses on the reinforcement and no-consequences levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 16 s; responses during the delay reset the interval. Presses on the no-consequences lever had no programmed effects.

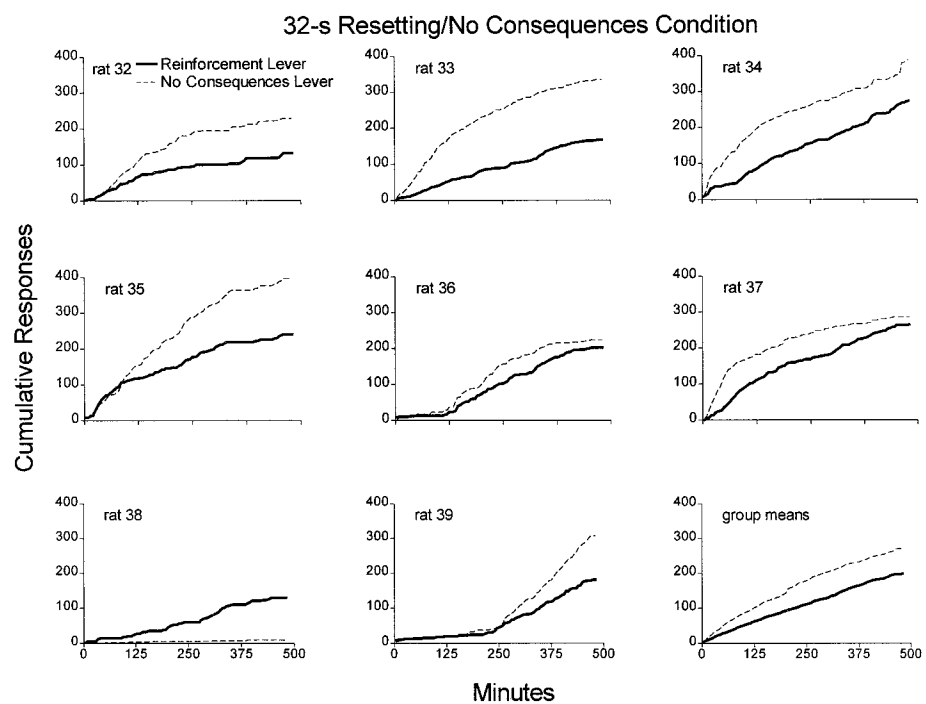


Fig. 5. Cumulative responses on the reinforcement and no-consequences levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 32 s; responses during the delay reset the interval. Presses on the no-consequences lever had no programmed effects.

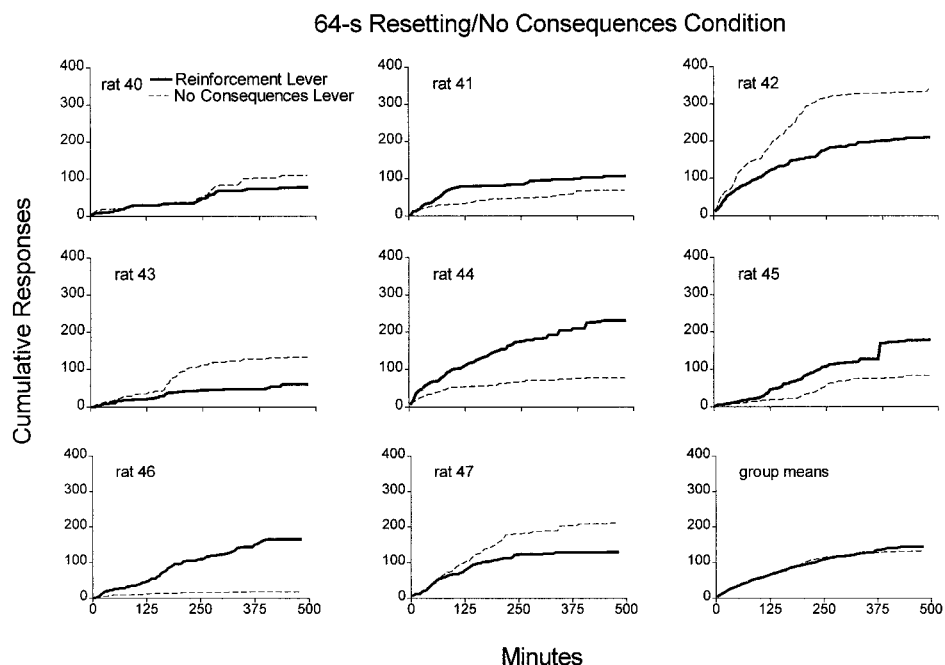


Fig. 6. Cumulative responses on the reinforcement and no-consequences levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 64 s; responses during the delay reset the interval. Presses on the no-consequences lever had no programmed effects.

RESULTS

Figures 1 and 2 depict the performance of subjects in the two control conditions. These and all other figures show cumulative responses on each lever over time for individual subjects and mean values for subjects as a group. Rats in the no-water condition emitted few responses on either lever; on average, they responded 34 times on each lever during the 8-hr session. All subjects in the immediate-reinforcement group showed clear evidence of response acquisition, responding substantially more on the reinforcement lever than on the no-consequences lever. On average, these rats responded over 200 times on the reinforcement lever during the 8-hr session and approximately 50 times on the no-consequences lever.

Resetting/No-Consequences Condition

Figures 3 through 6 depict performance under the resetting/no-consequences condition with delays of 8, 16, 32, and 64 s, respectively. When the delay was 8 s, 7 of 8 rats responded more often on the reinforcement lever than on the no-consequences lever. Performance in

these 7 animals was similar to that of subjects in the immediate-reinforcement group, with most responses occurring within the first one third of the session. With delays of 16 and 32 s, substantial levels of responding on the reinforcement lever were evident in most animals over the course of the session. When the delay was 16 s, however, only 3 of 8 rats responded more often on the reinforcement lever than on the no-consequences lever, and when it was 32 s, only 1 rat did so. If group means are considered, there was essentially no difference in responding on the two levers with a delay of 16 s. With a delay of 32 s, on average more responding occurred on the no-consequences lever than on the reinforcement lever. At delays of 32 s and shorter, all rats emitted more responses on the reinforcement lever than any rat in the no-water condition emitted on either lever.

When the delay was 64 s, 6 of 8 rats also responded more often on the reinforcement lever than any rat in the no-water condition did on either lever. Four of 8 animals in the 64-s delay group responded more often on the reinforcement lever than on the no-conse-

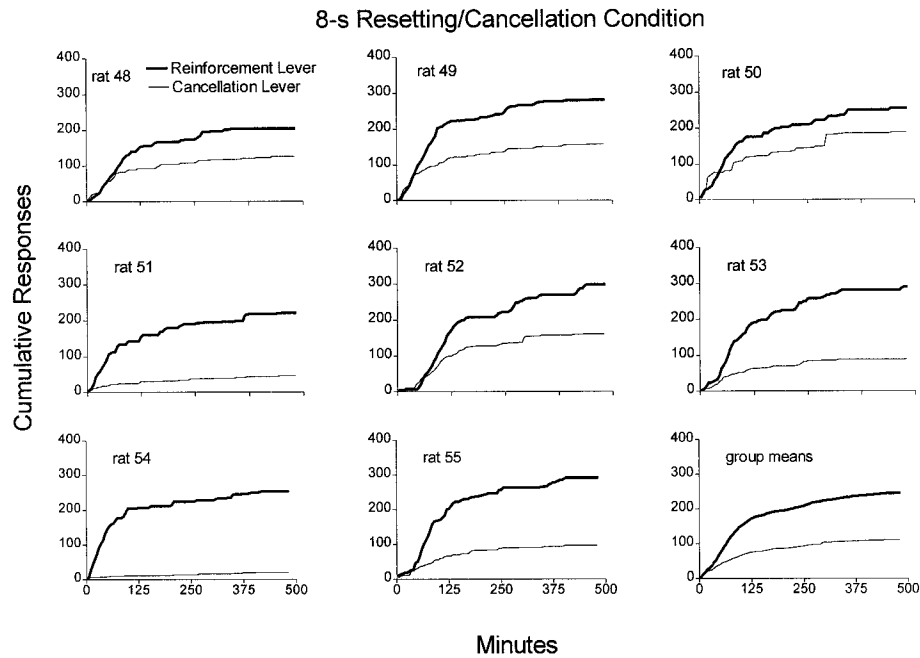


Fig. 7. Cumulative responses on the reinforcement and cancellation levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 8 s; responses during the delay reset the interval. Presses on the cancellation lever during a delay prevented delivery of the scheduled reinforcer (water); presses at other times had no programmed effects.

quences lever. When mean group performance is considered, there was no difference in responding on the two levers.

Resetting/Cancellation Condition

Results for subjects exposed to the reinforcement/cancellation condition are shown in Figures 7 through 10. When the delay was 8 s, all subjects showed clear evidence of response acquisition. They responded substantially more often on the reinforcement lever than on the cancellation lever; their performance did not differ appreciably from that of subjects in the immediate-reinforcement group, nor did it differ appreciably from that of subjects exposed to the resetting/no-consequences condition with a delay of 8 s.

When the delay was 16 s, all subjects responded more often on the reinforcement lever than on the cancellation lever, and there was an obvious difference in group means. A difference in mean levels of responding on the two levers was also apparent when the delay was 32 s; 5 of 8 rats responded more often on the reinforcement lever under this condition. At the 64-s delay, 4 subjects

emitted more responses on the reinforcement lever than any subject emitted on either lever in the no-water condition. But there was no difference in mean levels of responding on the two levers, and only 2 of 8 rats responded more often on the reinforcement lever than on the cancellation lever.

Table 1 shows total water deliveries for each subject in every group and group means. For subjects as a group, the number of water deliveries decreased as the delay increased. This relation held under both the resetting/no-consequences and resetting/cancellation conditions, which yielded similar data.

DISCUSSION

In a general sense, response acquisition occurs when behavior not previously established as operant is increased in rate of occurrence by its consequences. Previous studies have shown that the rate of lever pressing by experimentally naive rats increases over time when such responding produces food (or water) after delays of up to approximately 30 s

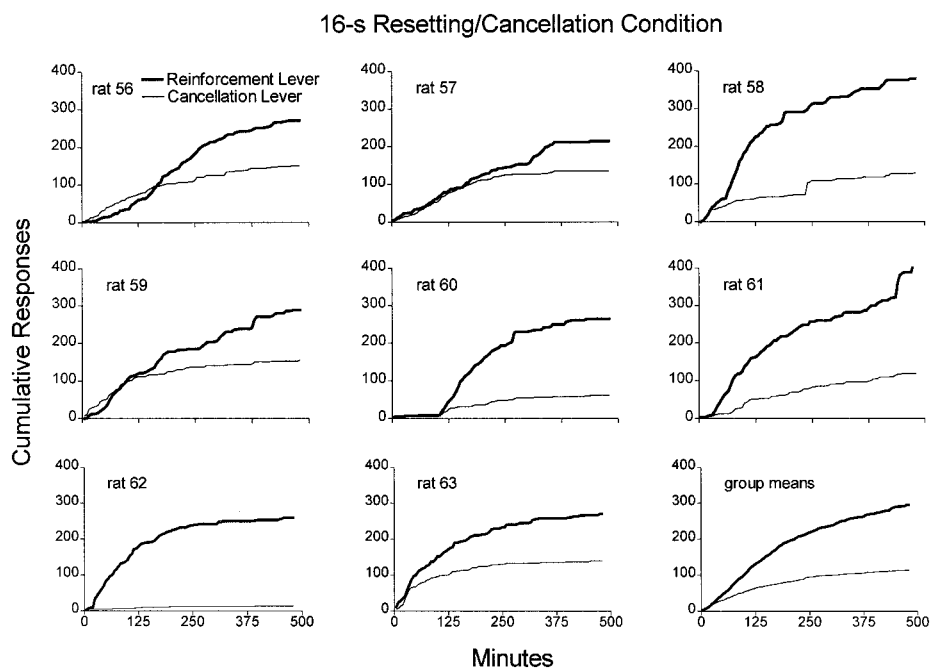


Fig. 8. Cumulative responses on the reinforcement and cancellation levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 16 s; responses during the delay reset the interval. Presses on the cancellation lever during a delay prevented delivery of the scheduled reinforcer (water); presses at other times had no programmed effects.

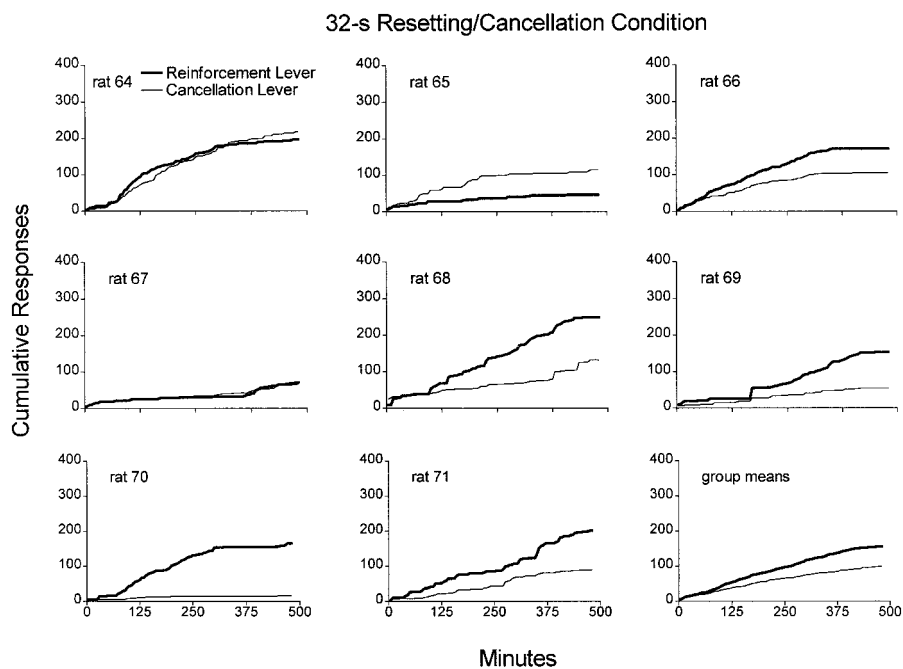


Fig. 9. Cumulative responses on the reinforcement and cancellation levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 32 s; responses during the delay reset the interval. Presses on the cancellation lever during a delay prevented delivery of the scheduled reinforcer (water); presses at other times had no programmed effects.

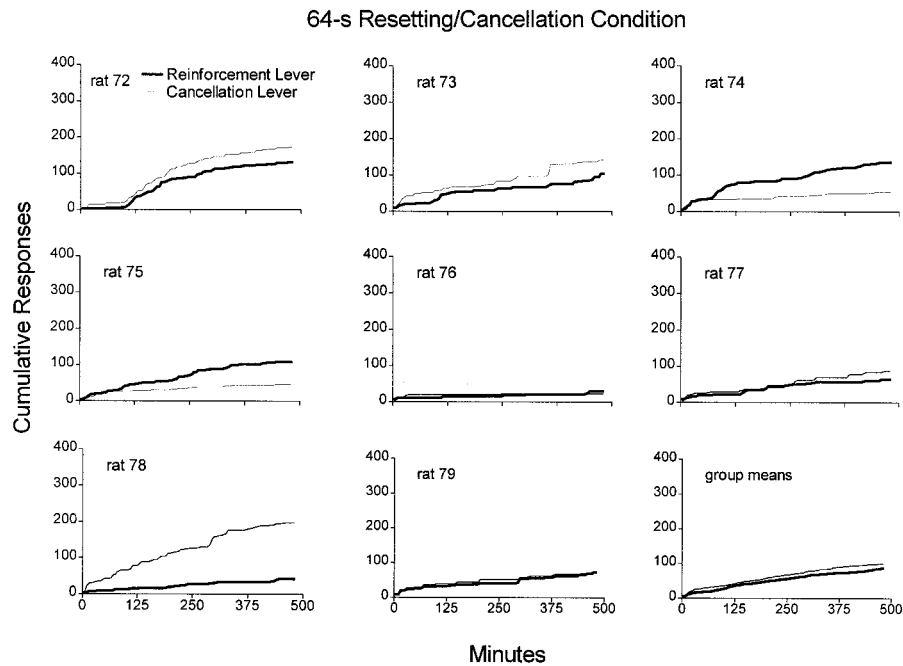


Fig. 10. Cumulative responses on the reinforcement and cancellation levers by individual rats across 8-hr sessions. Group means are also shown. Presses on the reinforcement lever produced water after a delay of 64 s; responses during the delay reset the interval. Presses on the cancellation lever during a delay prevented delivery of the scheduled reinforcer (water); presses at other times had no programmed effects.

(Byrne et al., 1997; Critchfield & Lattal, 1993; Dickinson et al., 1992; Lattal & Gleeson, 1990; LeSage et al., 1996; van Haaren, 1992; Wilkenfield et al., 1992). Two general procedures have been used to demonstrate that response-rate increases are due to the response-dependent delivery of food (or water), not to food or water delivery per se. One is a yoked-control procedure, which has been used by Dickinson et al. (1992) and LeSage et al. (1996). With this arrangement, yoked-control rats receive food when it is earned by a master partner, and lever presses by yoked-control subjects have no programmed consequences. Dickinson et al. reported that yoked-control rats responded significantly less frequently than master rats exposed to 16- and 32-s nonresetting delay procedures, and LeSage et al. reported similar results with an 8-s nonresetting delay procedure. These results provide evidence of operant control of lever pressing in the master animals. However, obtained delays under those procedures were shorter than nominal delays. With a nominal delay of 64 s, Dickinson et al. found no significant difference in the number of

lever presses emitted by master and yoked-control rats, unless the former were given prior exposure to the experimental chamber.

The present results under the resetting/cancellation procedure are similar to those obtained by Dickinson et al. (1992) in demonstrating that, with nominal delays of 16 and 32 s, more frequent responding occurs when lever presses produce a putative reinforcer than when they do not have this effect. An important procedural difference is that obtained and nominal delays were equivalent in the present study. Our results under the resetting/cancellation procedure also agree with those of Dickinson et al., in that we found little evidence of response acquisition with a 64-s delay. We did, however, observe that most rats pressed the reinforcement lever more often than any rat in the no-water control group pressed either lever, which could be construed as evidence of response acquisition. As Wilkenfield et al. (1992) indicate, the effects of delay on response acquisition depend, in part, on the procedures under which delay is evaluated and the mea-

Table 1
Total water deliveries for each rat.

Condition	Subject	Water deliveries	Condition	Subject	Water deliveries
No water			Immediate reinforcement		
	1	0		8	203
	2	0		9	216
	3	0		10	279
	4	0		11	193
	5	0		12	259
	6	0		13	267
	7	0		14	281
				15	222
	Group <i>M</i>	0		Group <i>M</i>	240
8-s resetting/no consequences			8-s resetting/cancellation		
	16	150		48	140
	17	151		49	159
	18	213		50	182
	19	175		51	150
	20	171		52	196
	21	174		53	184
	22	210		54	154
	23	158		55	144
	Group <i>M</i>	153.9		Group <i>M</i>	163.6
16-s resetting/no consequences			16-s resetting cancellation		
	24	141		56	144
	25	132		57	123
	26	119		58	144
	27	135		59	132
	28	171		60	119
	29	112		61	165
	30			62	153
	31	97		63	112
	Group <i>M</i>	129.6		Group <i>M</i>	136.5
32-s resetting/no consequences			32-s resetting/cancellation		
	32	65		64	56
	33	110		65	10
	34	134		66	78
	35	101		67	26
	36	94		68	86
	37	140		69	67
	38	74		70	86
	39	84		71	73
	Group <i>M</i>	100.3		Group <i>M</i>	60.3
64-s resetting/no consequences			64-s resetting/cancellation		
	40			72	29
	41	51		73	25
	42	79		74	52
	43	31		75	42
	44	70		76	8
	45	65		77	16
	46	82		78	11
	47	55		79	21
	Group <i>M</i>	61.9		Group <i>M</i>	25.5

sure of behavior used to index whether acquisition has occurred.

The least conservative approach to the study of acquisition involves measuring a single response and assuming that there is a re-

inforcement effect if the rate of that response increases across time when subjects are exposed to a procedure that involves delayed delivery of some consequence. As discussed previously, such an approach does not distin-

guish between reinforcing and other effects of the putative reinforcer. Yoked-control procedures allow such effects to be distinguished, and two-lever procedures are intended to do likewise. A possible advantage of two-lever procedures relative to yoked-control arrangements is that the former allow for within-subject analyses. Differential sensitivity across subjects to experimental events is a potential problem with between-subjects yoking procedures in general (Church, 1964), although the seriousness of this problem is debatable (see Gardner & Gardner, 1988). A serious practical problem does exist with yoked-control procedures, in that they double the number of subjects required to complete an experiment.

As discussed earlier, two-lever procedures in which responses on one lever have no programmed consequences raise significant issues of interpretation when resetting delays are programmed on the other lever. An issue not addressed is that of response induction from the no-consequences lever to the reinforcement lever. Responses on the former lever can be adventitiously followed by food (or water) with little or no delay, thereby establishing as conditioned reinforcers auditory, tactile, or proprioceptive stimuli associated with lever pressing (e.g., the sound of micro-switch operation, the feel of the lever moving). Presses on the resetting delay lever produce similar stimuli, and may be reinforced by them. Thus, the resetting/no-consequences condition allows for the possibility of immediate conditioned reinforcement of responses on the resetting lever, which is undesired in studies of reinforcement delay (Lattal, 1987; Schlinger & Blakely, 1994).

The resetting/cancellation procedure avoids this problem. It also provides unambiguous evidence that consequences delayed by up to approximately 30 s affect behavior. This result is consistent with, and bolsters, prior findings (Byrne et al., 1997; Critchfield & Lattal, 1993; Dickinson et al., 1992; Lattal & Gleeson, 1990; LeSage et al., 1996; van Haaren, 1992; Wilkenfield et al., 1992). This delay value should, of course, not be construed as some limit beyond which reinforcement becomes ineffective. Four of 8 rats in the present study provided some evidence of response acquisition with reinforcement delayed by 64 s, and the results reported by

Dickinson et al. (1992) suggest that seemingly small differences in procedure can substantially influence response acquisition with long delays of reinforcement. Under conditions that vary somewhat from those of the present experiment, or with longer exposure to the present conditions, consistent acquisition may occur with delays of a minute or more.

Procedures similar to those originated by Lattal and Gleeson (1990) have been used to evaluate the effects of drugs on the initial response-strengthening effects of reinforcement (Byrne et al., 1997; LeSage et al., 1996). It is noteworthy in this regard that Byrne et al., who compared the effects of chlorpromazine under immediate-reinforcement and 8-s nonresetting delay procedures, found that delay modulated the effects of chlorpromazine when performance was indexed by comparing responses on the reinforcement and no-consequences levers. There was, however, no clear indication that delay modulated the drug's effect on reinforcement-lever response rates alone. The reinforcement/cancellation procedure has not been used to examine reinforcement delay as an influence on drug effects, but is of interest in this context because it allows different delays to be compared under conditions in which learning is clearly occurring.

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Received May 30, 1997

Final acceptance September 3, 1997